Retrospective Estimates of Interannual and Decadal Variability in Lower Trophic Level Production in the Hecate Strait-Queen Charlotte Sound Region from 1958 to 1998

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RETROSPECTIVE ESTIMATES OF INTERANNUAL AND DECADAL VARIABILITY IN LOWER TROPHIC LEVEL PRODUCTION IN THE HECATE STRAIT-QUEEN CHARLOTTE SOUND REGION FROM 1958 to 1998

by

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ABSTRACT

Ware, D., and McQueen, D. 2006. Retrospective estimates of interannual and decadal variability in lower trophic level production in the Hecate Strait-Queen Charlotte Sound region from 1958 to 1998. Can. Tech. Rep. Fish. Aquat. Sci. 2656: vii + 31 p.

The work summarized in this report involved reconstructing daily time series of sea surface temperature, hours of bright sunlight and daily alongshore wind speeds in the Hecate Strait region from 1958 to 1998. The objective was to force the newest version of the NPZ model with a number of important variables derived from these climate time series to provide daily (and annual) estimates of production and biomass for phytoplankton, "spring" zooplankton, copepods and euphausiids from 1958-1998. For the period 1958-1998, the model estimates that the primary production averaged about 223 g $C \cdot m^{-2} \cdot yr^{-1}$, and that the zooplankton converted the net primary production into zooplankton production with an average ecological efficiency (total zooplankton production/net primary production) of 10%. Also, zooplankton production was more variable than the primary production, and euphausiid and copepod functional groups were more variable than spring zooplankton. Annual net primary production was most highly correlated with average upwelling wind speed during the production season. Annual production of the combined zooplankton was most highly correlated with the net primary production ($r^2 = 0.75$), and with the average upwelling wind speed ($r^2 = 0.39$). Euphausiid production was most highly correlated with net primary production ($r^2 = 0.76$), and the average upwelling wind speed ($r^2 = 0.38$). In the model, the annual production of euphausiids was also highly correlated with the annual production of copepods ($r^2 = 0.92$).

RÉSUMÉ

Ware, D., and McQueen, D. 2006. Retrospective estimates of interannual and decadal variability in lower trophic level production in the Hecate Strait-Queen Charlotte Sound region from 1958 to 1998. Can. Tech. Rep. Fish. Aquat. Sci. 2656: vii + 31 p.

Ce rapport résume les travaux nécessaires au rétablissement des séries chronologiques quotidiennes de la température de l'eau en surface, des heures d'ensoleillement et de la vitesse du vent le long des côtes dans la région du détroit d'Hécate entre 1958 et 1998. L'objectif consistait à utiliser un certain nombre de variables importantes dérivées de ces séries chronologiques climatologiques dans la nouvelle version du modèle du zooplancton, du phytoplancton et des éléments nutritifs en fonction du climat dans le détroit d'Hécate pour obtenir des estimations quotidiennes (et annuelles) de la production et de la biomasse de phytoplancton, de zooplancton printanier, de copépodes et d'euphausiacés pour la période de 1958 à 1998. Le modèle a permis d'estimer que la production primaire était en moyenne de 223 g C par m^2 par année et que l'efficacité écologique moyenne du zooplancton (production zooplanctonique totale / production primaire nette) se chiffrait à 10 %. De plus, la production de zooplancton variait davantage que la production primaire, et les groupes fonctionnels des copépodes et des euphausiacés variaient davantage que le zooplancton printanier. La production primaire nette annuelle était corrélée le plus étroitement à la vitesse moyenne du vent qui favorise la remontée d'eaux froides durant la saison de production. La production annuelle de l'ensemble du zooplancton était corrélée le plus étroitement à la production primaire nette ($r^2 = 0,75$) et à la vitesse moyenne du vent qui favorise la remontée d'eaux froides ($r^2 = 0,39$). La production d'euphausiacés était corrélée le plus étroitement à la production primaire nette ($r^2 = 0,76$) et à la vitesse moyenne du vent qui favorise la remontée d'eaux froides ($r^2 = 0,38$). La production annuelle d'euphausiacés était également étroitement corrélée à la production annuelle de copépodes ($r^2 = 0,92$).

INTRODUCTION

A principal objective of the "Ecosystem Approach to Fisheries Management in Hecate Strait" project led by Fisheries and Oceans Canada (DFO) is to increase existing knowledge about the major factors affecting the productivity of commercial marine fisheries in the Hecate Strait region by investigating the relative influences of fishing, environmental, and biological processes on the population dynamics and distribution of marine fishes. The purpose of the lower trophic level modeling component of this project is to: A) develop a dynamic climate-forced model of the Hecate Strait pelagic ecosystem that can be used to estimate lower trophic level productivity in the region, B) retrospectively diagnose how ocean climate variations and trends in the 1990s may have affected lower trophic level productivity and the seasonal timing of important biological events, and C) explore how the Hecate Strait ecosystem may have responded to changes in climatic conditions over the last four decades. Our earlier reports (McQueen and Ware 2006; Ware and McQueen 2006) addressed the first two objectives. This report focuses on the third objective which is the retrospective analysis.

The work summarized in this report involved reconstructing daily time series of sea surface temperature (SST), hours of bright sunlight and daily alongshore wind speeds in the Hecate Strait region from 1958 to 1998. Electronic data files associated with this report are listed in Appendix D and are available upon request. The objective was to force the newest version of the Nutrient/Phytoplankton/Zooplankton (NPZ) model with a number of important variables derived from these climate time series to provide daily (and annual) estimates of production and biomass for phytoplankton, "spring" zooplankton, copepods and euphausiids from 1958-1998. The resulting plankton biomass and production time series will be compared by the ECOSIM modeling group with the top-down derived outputs from the Hecate Strait ECOSIM model that is also being developed in the Hecate Strait Project. In addition, the NPZ model output time series will also be used to provide bottom-up forcing to the ECOSIM model.

Brief Description of the Hecate Strait NPZ Model

The modeling approach taken here is to develop a dynamic simulation model which tracks the flow of biomass from the bottom of the food web (phytoplankton), through copepods, euphausiids, and other key zooplankton to higher order predators in the system. The current version of the model is forced by a suite of climatic factors which regulate phytoplankton production through water temperature, hours of sunlight, wind mixing, and upwelling. The last two factors affect nutrient availability, which is extremely important. Daily values of day length, hours of bright sunshine, SST, upwelling wind speed, and mixing depth are input to the model starting 1 March (Day 60) and ending 30 November (Day 334). Virtually all of the annual production occurs during this period. See Ware and McQueen (2006) for a detailed description of the model.

The net rate of primary production (mg $C \cdot m^{-3} \cdot d^{-1}$) is determined by the biomass and depth distribution of the phytoplankton, plus the available Photosynthetically Active Radiation (PAR) and nitrogen at depth. The model calculates the average depth (m) of

the phytoplankton each day as the result of sinking and wind mixing. Sinking rates are typically about 0.1-1.0 $m \cdot d^{-1}$ (Ziemann *et al* 1990). In the model, wind mixing can either increase or decrease the depth of the phytoplankton depending on the intensity of mixing.

The model explicitly considers three functional groups of zooplankton: "spring" zooplankton, copepods, and euphausiids. Abundance information about the different zooplankton species is available from a number of sources (McQueen and Ware 2006). Appendix A summarizes how the zooplankton data were standardized and sorted into the three functional groups in the model.

We assume that most of the "spring" zooplankton biomass is herbivorous because this group dominates the zooplankton community during the spring bloom. We also assume that the copepods are primarily herbivorous. A formulation of the daily specific grazing rate of the spring zooplankton and copepods was guided by data contained in McAllister (1970) and Frost (1987). We used a Michaelis-Menten functional response because it fits the experimental data, as well as other models that have been used to calculate zooplankton feeding rates.

Daily and cumulative production rates for each zooplankton group are estimated in the model by summing the daily growth rates and "integrating" over depth by assuming that all grazing takes place in the euphotic zone during the production season.

The version of the model used for the retrospective analysis (*Colim436*) is a slightly modified version of the previous model (*Colim434*) described in our 2006 report (Ware and McQueen 2006). The newest version fixes some weaknesses of the previous model. For example, the zooplankton ecological efficiency in the older version of the model was a little too high, and the primary production was a little too low. The latest version of the model (*Colim436*) corrects these and other anomalies.

METHODS

Development of the Long-term (1958-1998) Climate Data File for Hecate Strait

The Hecate Strait long-term data file was assembled using information from three sources. The *first* source comprised daily data for "hours of bright sunlight" at Port Hardy and/or Sandspit. Due to constraints imposed by data availability, Sandspit data were used from January 01, 1958 through to April 30, 1971 and Port Hardy data were used from May 01, 1971 through December 31, 1998. The *second* data source comprised sea surface temperature (SST) data from McInnes Lighthouse which is located on the east side of Hecate Strait near Buoy 46185 (hereafter referred to as "Buoy 185"). This data set provides hourly salinity and SST data for McInnes Island from 1954 through 2003. The *third* data set, termed the "Faucher Wind" data set, was developed by Manon Faucher in conjunction with oceanographers at the Institute of Oceans Sciences (IOS) in Sydney, B.C. and the University of British Columbia. It provides simulated wind velocity and direction data for Buoys 004, 036, 184, 132, 145, 147, 183, 185, 204, 205,

206, 207 and 208 on the Pacific coast of North America. The methods used to develop these data are described in a manuscript available from Bill Crawford at IOS. The Faucher data set provides data every six hours for: date (1958-1998), mean U (east-west $m \cdot s^{-1}$), mean V (north-south $m \cdot s^{-1}$), mean daily wind speed ($m \cdot s^{-1}$), and mean daily wind direction (degrees). For the Hecate Strait model, we used data from Buoy 185.

Once assembled, the data sets were edited in several ways:

1) Hourly data for bright sunlight, hourly data for SST, and six-hourly data for Faucher V wind velocity were averaged to produce mean daily values.

2) Daily hours of bright sunlight data were then used without further modification except that missing values for all of April 1995 and all of February 1997 were estimated by substituting mean daily values averaged over 10 years (1990-1999).

3) Daily SST data from McInnes Lighthouse were corrected in two ways. First, it was observed that some McInnes SST values were <6°C during mid-winter. This was never observed at Buoy 185, and so all McInnes values <6°C were made to equal 6°C. Second, the corrected McInnes Lighthouse SST data were again correlated with SST data collected from 1992-1998 at Buoy 185. The resulting regression plot (Fig. 1) suggested that the 1992-1998 McInnes Island data averaged 0.7°C less than the 1992-1998 Buoy 185 data, and therefore the McInnes data set were corrected by adding 0.7°C to each value. The resulting plot (Fig. 2) suggested that the correction brought the two data sets into good agreement.

4) The V wind velocity ($m \cdot s^{-1}$) data from the Faucher data set required one adjustment. When mean daily 1992-1998 Faucher V wind velocity was regressed against V measured at Buoy 185 (1992-1998), the resulting relationship (Fig. 3) showed that at high Buoy 185 V wind velocities, the Faucher V values were too low. Faucher V values were also too high at low Buoy 185 V wind velocities.

The relationship is:

$$\text{Faucher V} = 0.370761 + 0.712639(\text{Buoy V}) \qquad \text{Eq. 1}$$

Using this relationship, we estimated mean Faucher V with respect to measured Buoy V (Fig. 4).

We then calculated the average deviation between Faucher V and measured Buoy V for 1992-98 (Fig. 5). The relationship is:

$$\text{Deviation} = 0.40324(\text{Faucher V}) - 0.52026. \qquad \text{Eq. 2}$$

When Faucher V is negative the deviation is negative. When Faucher V is positive the deviation is positive. When the deviation is applied to the Faucher V data,

the effect is to increase the slope, which corrects for the bias observed in Figure 3. As seen in Figure 6, this corrected relationship provides a much improved fit between mean daily 1992-1998 Faucher V and mean daily measured Buoy 185 V (regression $p < 0.001$). The correction described in Figure 5 was applied to all mean daily Faucher V, completing all of the bias corrections applied to the original data set.

In summary, the long-term (1958-1998) Hecate Strait data set includes SST data from McInnes Island, hours of bright sunlight data from Sandspit and Port Hardy, and Faucher V wind velocity data. Biases in the SST and Faucher V data were removed by comparing both to 1992-1998 data obtained from Buoy 185 and applying appropriate corrections. These were then applied to the entire 1958-1998 long-term data set. The completed data set includes 13 parameters:

C1 = Year

C2 = DAY. Numerical day of the year (1 = Jan. 1; 365 = Dec. 31).

C3 = Faucher U wind speed (daily mean, $m \cdot s^{-1}$).

C4 = Faucher V wind speed (daily mean, $m \cdot s^{-1}$). Positive alongshore wind speeds (downwelling-favourable) indicate that the wind is blowing northward from the SE. Negative wind speeds (upwelling-favourable) indicate that the wind is blowing southward from the NW.

C5 = Faucher mean wind speed (daily mean, $m \cdot s^{-1}$).

C6 = Faucher mean wind direction (daily mean direction, degrees).

C7 = SST. Daily sea surface temperature (°C) at McInnes Island Lighthouse.

C8 = HBS. Daily hours of bright sunlight at Port Hardy and Sandspit.

C9 = A-Wind. Daily average, alongshore wind speed ($m \cdot s^{-1}$). All the data in this column are absolute values of the data in C4.

C10 = UPWEL-Wind. Daily Upwelling wind speed ($m \cdot s^{-1}$). Data in this column include only the negative sign (NW winds) values in C4. When the wind was blowing from the SE, a "0" is inserted in C10. The data in this column indicate the speed of the upwelling-favourable northwesterly wind.

C11= Delta SST. Daily Delta Temperature (°C). C11 = C7 - 6.

C12 = Mixing Depth. Daily mixing Depth (m) at model location.
$C12 = 4.77(C11)^{-0.714}(C9)^{1.28}$

C13 = ME Depth. Deep mixing event depth (m). This column contains the mixing depth for all the days in C12 when the depth of mixing was ≥ 30m. If the estimated mixing depth was less than 30 m, a "0" entry is inserted in C13.
$C13 = 4.77(C11)^{-0.714}(C9)^{1.28}$

Model Input Time Series

Five of the above mentioned time series were used to provide daily forcing to the model. These were: A) average sea surface temperature, B) daily hours of bright sunlight, C) average alongshore wind speed, D) average upwelling wind speed, and E) average depth of mixing. The interannual variability and the lower frequency decadal trends in the average values of these variables during the production season (1 March to 30 November) are shown in Figures 7-11.

The low frequency decadal trends shown in Figures 7-11 indicate that both the average upwelling-favourable wind speed and alongshore wind speed declined in the 1960s, reached a minimum in the early 1970s, then increased for the next 25 years and reached a peak in the early 1990s. The average sea surface temperature trend was very similar to the wind time series, except that average SST remained anomalously warm up to 1998. As expected, the average mixing depth (Fig. 9) varied inversely with the wind and SST time series. When the average SST was high, the upper layer was more stratified and required strong winds to mix the surface waters to deeper depths. Although there was significant interannual variability in the hours of bright sunlight, there were no pronounced decadal trends in this aspect of the climate.

Table 1 summarizes the March-November means and interannual variability in the climate time series for 1958-1998 (41 years). The results show that the most variable component of the climate during this period was the average upwelling wind speed. The second most variable component was the average mixing depth.

RESULTS AND DISCUSSION

In the following sections, we first use data for the 1990s to compare outputs from two versions of the model and two data sets (Buoy data and Faucher data). We then compare 1998-1999 chlorophyll outputs with field data from the SeaWiFS satellite. Finally, we use the "Faucher wind" data set and the most recent version of the model (*Colim436*) to generate daily and annual outputs for the period 1958-1998.

Comparison of *Colim434* and *Colim436* Model Outputs

Table 2 summarizes the annual estimates of primary and secondary production produced by the previous version of the model (*Colim434*) and the latest version (*Colim436*), for the two different wind time series in the 1990s. Model *Buoy_Colim434* was the version of the model used in our 2006 report (where it is referred to as *Model v4.3.4*). Modifications to that model lead to version *Buoy_Colim436*, which we believe is generally superior to the *Buoy_Colim434* version based on a diagnostic comparison of model output.

Tables 3 and 4 summarize the correlations in primary and secondary production for three different versions of the model for the 1990s. Table 3 indicates that the highest

correlation in the estimates of primary production is for the two models which have the same biological structure (*Colim436*), but are being forced by slightly different ocean climate data (Buoy or Faucher time series). In this case, the correlation is also high for the two models that have slightly different biological structure (*Colim434* and *Colim436*), but are forced by the same ocean climate data (Buoy; see Appendix D to obtain the Excel spreadsheet "*Buoy185 ocean climate data.xls*").

Table 4 summarizes the correlation coefficients for the annual zooplankton production produced by the three models. The results are similar to Table 3. However, in this case the correlation between the output produced by the two different versions of the model (*Colim434* and *Colim436*) is not as high.

The correlations between the *Buoy_Colim436* and *Faucher_Colim436* estimates of copepod and euphausiid production were lower (r^2 = 0.32 and 0.29 respectively). This highlights the fact that in the model, these functional groups are very sensitive to oceanic and biological conditions in the summer and fall. Slight variations in these conditions can have a measurable impact on production.

We conclude from this comparison that the output produced by the model using the Faucher retrospective wind time series (*Faucher_Colim436*) yields comparable results as the same version of the model that is forced by the wind data measured at meteorological Buoy 185 (*Buoy_Colim436*).

Comparison of Model *Colim436* Chlorophyll Estimates with SeaWiFS Data

As noted above, we believe that the *Colim436* version of the model produces more realistic estimates of primary production than the earlier (*Colim434*) version. Figures 12 and 13 show how well the monthly estimates of surface chl *a* ($mg \cdot m^{-3}$) produced by model *Buoy_Colim436* compare with empirical measurements made by the SeaWiFS satellite for 1998 and 1999 in the Hecate Strait region. The model does a reasonable job of capturing the timing and amplitude of the spring bloom in 1998, but it underestimates the surface chl *a* concentration in the fall. For 1999, the model reproduces the magnitude of the seasonal change in chl *a* concentrations, except for the obvious phase shift. According to the satellite measurements, the spring bloom peak occurred about a month later than the model estimate. However, the model successfully predicted that the spring bloom peak should have been later in 1999 than it was in 1998.

Variability in Lower Trophic Level Production

Table 5 summarizes the long-term means, ranges and coefficients of variation (CV) of the production of each functional group in the model.

Over the last four decades, the model estimates that the primary production averaged about 223 g $C \cdot m^{-2} \cdot yr^{-1}$, and that the zooplankton converted the net primary production into zooplankton production with an average ecological efficiency (total zooplankton production/net primary production) of 10%. Table 5 also indicates that the zooplankton production is more variable than the primary production, and that the

euphausiid and copepod functional groups appear to be more variable than the "spring" zooplankton.

The interannual variability and decadal trends in primary and secondary production from 1958-1998 are shown in Figures 14-18.

Although the decadal trends in primary and zooplankton production are broadly similar, there are some important differences. Primary production was low in the 1960s, increased in the 1970s and 1980s, peaked in the early 1990s, and then declined slightly in the mid-to-late-1990s. Total zooplankton production and "spring" zooplankton production declined in the 1960s, was low in the 1970s, and then increased in the 1980s and 1990s. Copepod and euphausiid production declined in the 1960s and 1970s, increased in the 1980s, peaked in the early 1990s, and then declined slightly in the mid-to-late-1990s.

Relationships between Ocean Climate Variables and Lower Trophic Level Production

Over the length of the 41-year time series, the annual net primary production was most highly correlated with the average upwelling wind speed during the production season (Fig. 19; $r^2 = 0.58$; $p < 0.001$). This is expected given the importance of upwelling in supplying new nitrogen to the photic zone, particularly in the summer. However, the moderate value of r^2 indicates that many other factors like sunlight, wind mixing, and zooplankton grazing are also important. Primary production was weakly negatively correlated with the average sea surface temperature during the production season ($r^2 = -0.01$).

The annual production of the combined zooplankton was most highly correlated with the net primary production (Fig. 20; $r^2 = 0.76$), and with the average upwelling wind speed ($r^2 = 0.38$).

Surprisingly, the production of the "spring" zooplankton was most highly correlated with the average sea surface temperature (Fig. 21; $r^2 = 0.63$; $p < 0.0001$). The correlation with the annual net primary production was much weaker ($r^2 = 0.09$). The production of the "spring" zooplankton was uncorrelated with copepod production ($r^2 \approx 0$) or euphausiid production ($r^2 \approx 0$).

In the model, the copepod component primarily represents the medium and small-sized copepod species that are most abundant during summer in the Queen Charlotte Sound region. It is not surprising that copepod production in the model was most highly correlated with net primary production ($r^2 = 0.62$), and also with average upwelling wind speed ($r^2 = 0.29$) which is the principal physical factor that forces primary production in the summer.

Euphausiid production was most highly correlated with net primary production ($r^2 = 0.76$) and the average upwelling wind speed ($r^2 = 0.37$). In the model, the annual production of euphausiids was also highly correlated with the annual production of copepods ($r^2 = 0.92$).

With respect to the efficiency with which the zooplankton convert primary production into zooplankton production, the model suggests that the ecological efficiency increases significantly with SST (Fig. 22; $r^2 = 0.42$; $p < 0.0001$). This occurs in the model because the grazing rates of the zooplankton increase exponentially with temperature. Consequently, zooplankton become more efficient phytoplankton grazers at higher temperatures.

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Table 1. March-November means and interannual variability in the climate time series between 1958-1998 (41 years).

Variable	Mean	Range	Coefficient of Variation
Sea surface temperature (°C)	11.24	2.22	0.043
Hours of sunlight (hrs·day^{-1})	4.72	3.18	0.116
Alongshore wind speed (m·s^{-1})	5.38	1.23	0.051
Upwelling wind speed (m·s^{-1})	2.01	2.42	0.255
Stability index (°C)	5.25	2.21	0.093
Mixing depth (m)	17.52	12.2	0.149

Table 2. Comparison of primary and zooplankton production (g C·m^{-2}·yr^{-1}) estimated by different Models (Versions 434 and 436) and wind forcing time series (Buoy and Faucher datasets). Model versions which use the Buoy data are considered to provide better estimates.

Model	Primary Production (g C·m^{-2}·yr^{-1})	Zooplankton Production (g C·m^{-2}·yr^{-1})			
		"Spring" Zooplankton	Copepod	Euphausiid	Total Zooplankton
91BuoyColim434	190	18.8	5.4	11.0	35.2
91BuoyColim436	240	13.3	3.6	7.7	24.6
91FaucherColim436	293	10.7	4.6	11.1	26.4
92BuoyColim434	193	19.6	2.6	6.7	28.9
92BuoyColim436	222	13.7	2.7	7.1	23.4
92FaucherColim436	276	15.5	3.7	8.75	27.9
93BuoyColim434	207	18.7	3.5	11.5	33.7
93BuoyColim436	225	11.2	2.3	7.6	21.0
93FaucherColim436	242	13.7	2.4	7.1	23.2
94BuoyColim434	154	18.1	1.9	3.2	23.3
94BuoyColim436	172	14.3	1.5	2.5	18.3
94FaucherColim436	201	16.1	1.7	3.4	21.2
95BuoyColim434	176	23.3	3.6	5.5	32.4
95BuoyColim436	203	19.1	2.4	3.7	25.3
95FaucherColim436	264	16.7	5.3	10.3	32.5
96BuoyColim434	161	17.9	2.8	5.0	25.7
96BuoyColim436	184	13.8	2.1	3.7	19.6
96FaucherColim436	248	14.7	4.0	7.6	26.3
97BuoyColim434	170	22.8	3.0	4.6	30.4
97BuoyColim436	159	14.6	1.1	2.1	17.7
97FaucherColim436	218	17.5	2.6	6.6	26.7
98BuoyColim434	202	23.0	1.8	4.4	29.2
98BuoyColim436	190	23.9	1.8	5.0	30.1
98FaucherColim436	280	25.7	4.3	8.6	38.6

Table 3. Annual net primary production (g $C \cdot m^{-2} \cdot yr^{-1}$) correlation coefficients for the 1990s.

Model Version	Buoy_Colim434	Buoy_Colim436
Buoy_Colim434	1.00	.
Buoy_Colim436	0.68	1.00
Faucher_Colim436	0.64	0.73

Table 4. Annual zooplankton production (g $C \cdot m^{-2} \cdot yr^{-1}$) correlation coefficients for the 1990s.

	Buoy_Colim434	Buoy_Colim436
Buoy_Colim434	1.00	.
Buoy_Colim436	0.38	1.00
Faucher_Colim436	0.19	0.86

Table 5. Model estimates of the long-term means and variability in primary and zooplankton production (all in g $C \cdot m^{-2} \cdot yr^{-1}$) in the Hecate Strait-Queen Charlotte Sound region for 1958-1998.

Variable	Mean	Range	CV
Net primary production	223	151 - 374	0.22
Total zooplankton production	23.5	15.1 - 46.7	0.30
"Spring" zooplankton production	14.1	5.5 - 25.7	0.29
Copepod production	3.1	0.43 - 6.7	0.53
Euphausiid production	6.3	0.43 - 17.0	0.63
Zooplankton ecological efficiency	0.10	0.08 - 0.14	0.14

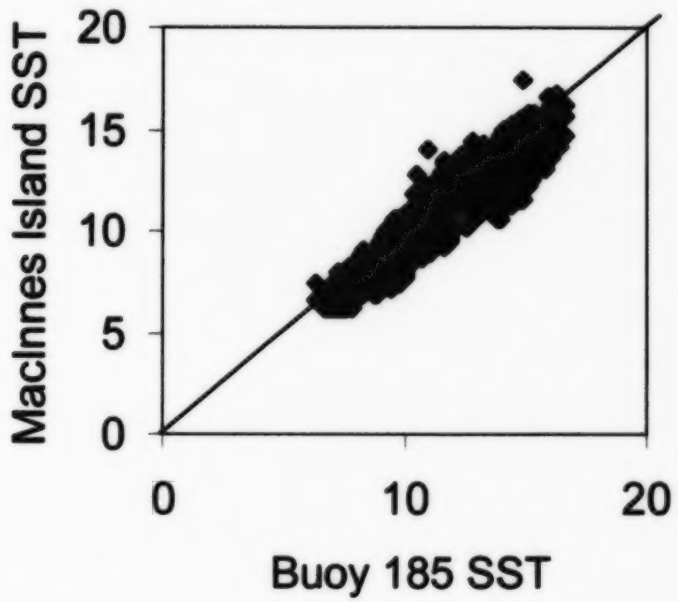

Figure 1. Uncorrected McInnes SST (°C) with respect to Buoy 185 SST (°C).

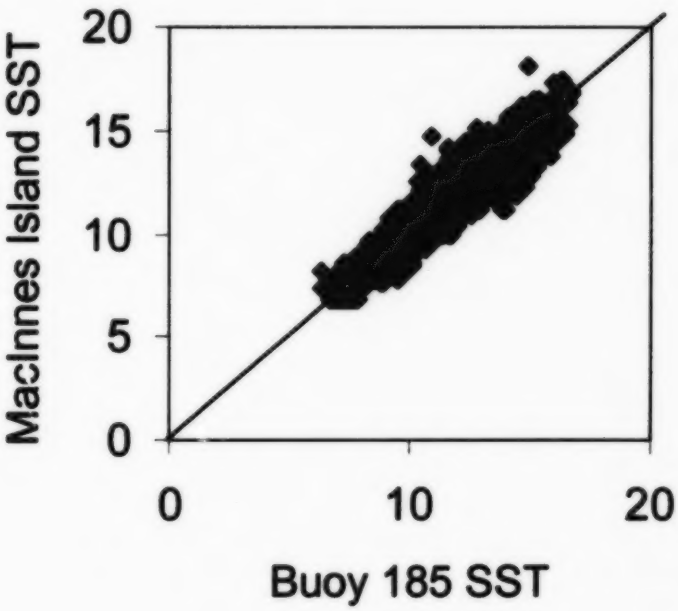

Figure 2. Corrected M Innes SST (°C) with respect to Buoy 185 SST (°C).

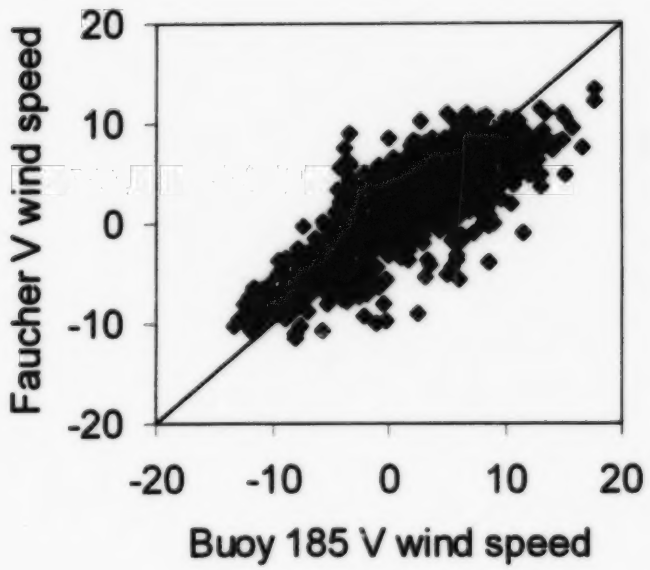

Figure 3. Daily Faucher V wind speed ($m \cdot s^{-1}$) with respect to Buoy 185 V ($m \cdot s^{-1}$) for 1992-1998.

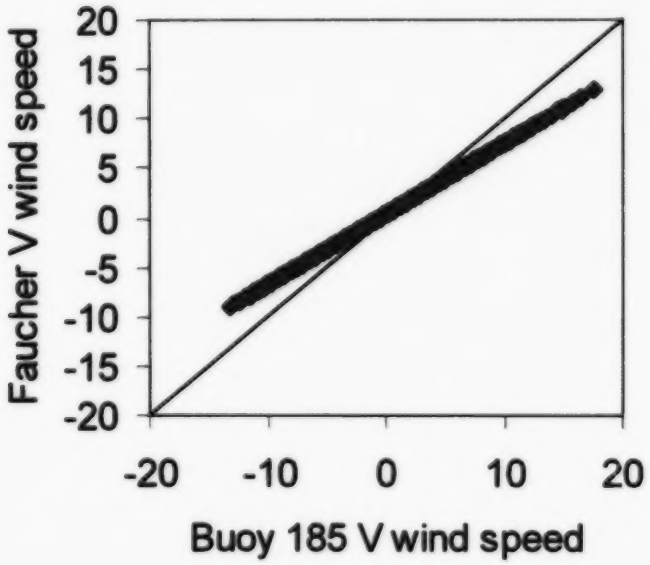

Figure 4. Mean Faucher V wind speed ($m \cdot s^{-1}$) with respect to Buoy 185 V ($m \cdot s^{-1}$) measured during 1992-1998.

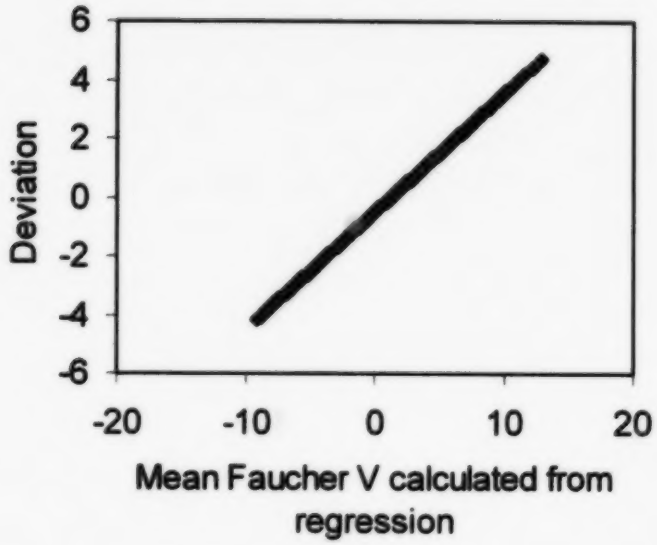

Figure 5. Deviation of mean daily Faucher V wind speed ($m \cdot s^{-1}$) from mean daily Buoy 185 V wind speed ($m \cdot s^{-1}$) measured during 1992-1998.

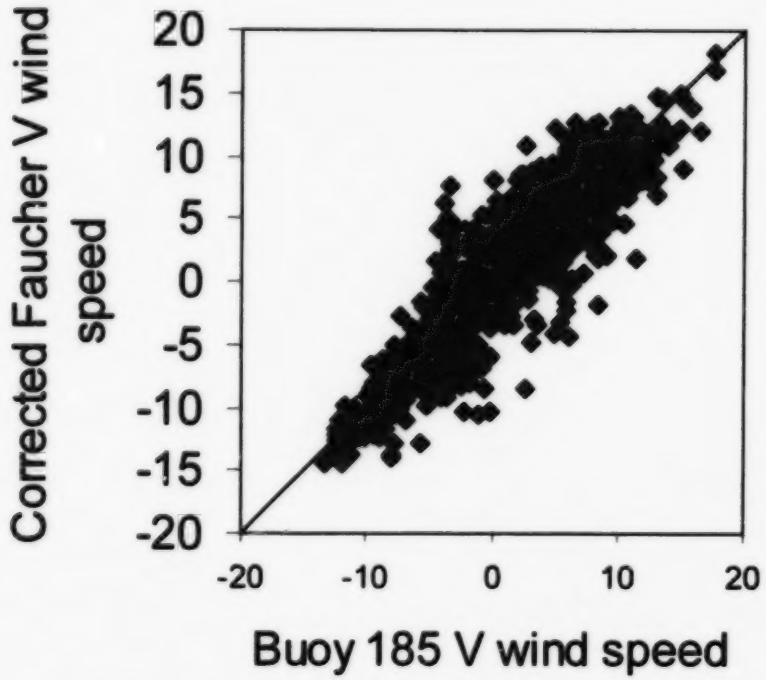

Figure 6. Corrected mean daily Faucher V wind speed ($m \cdot s^{-1}$) with respect to mean daily V wind speed ($m \cdot s^{-1}$) measured at Buoy 185 for 1992-1998.

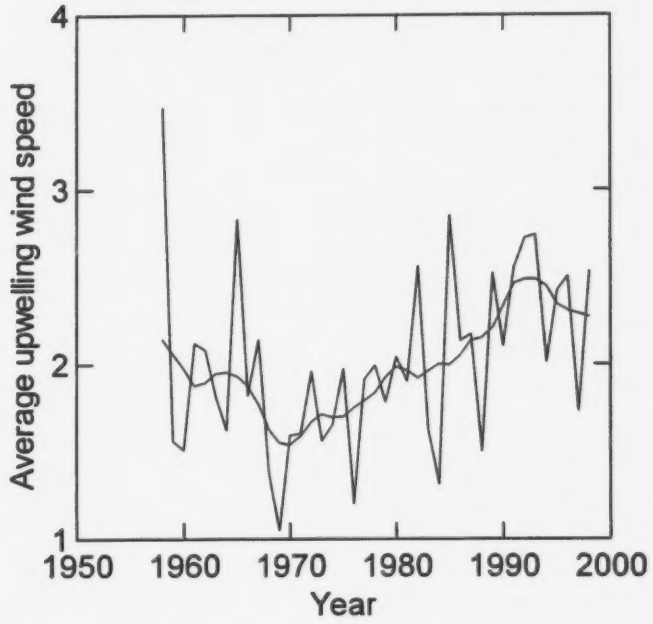

Figure 7. March-November average upwelling wind speed ($m \cdot s^{-1}$) for 1958-1998 at Buoy 185.

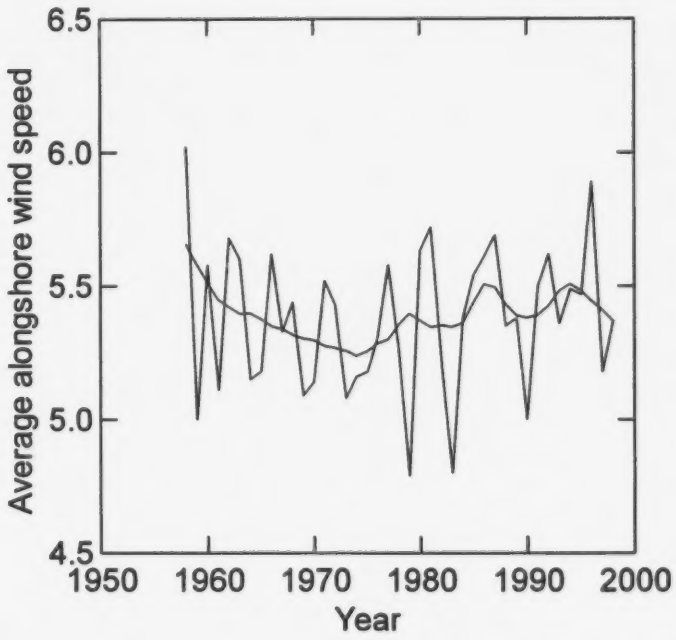

Figure 8. March-November average alongshore wind speed ($m \cdot s^{-1}$) for 1958-1998 at Buoy 185.

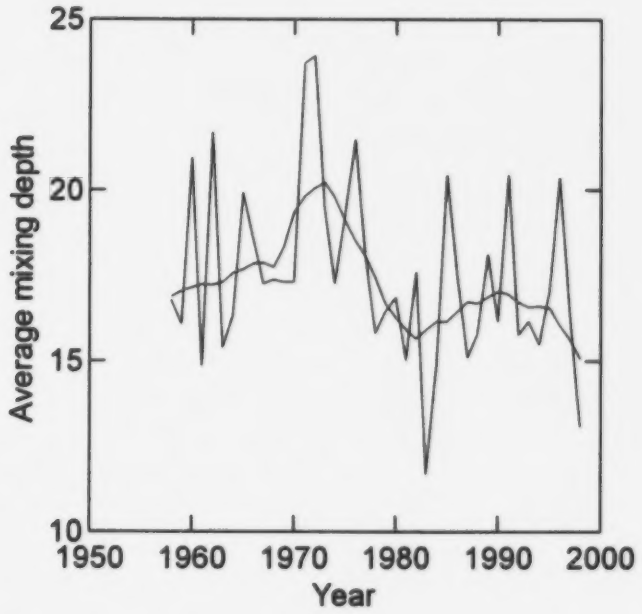

Figure 9. March-November average mixing depth (m) for 1958-1998 at Buoy 185.

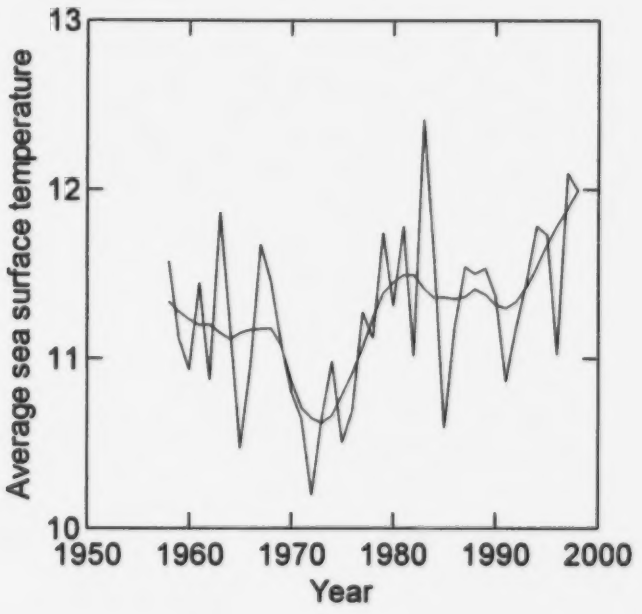

Figure 10. March-November average sea surface temperature (°C) from 1958-1998 at Buoy 185.

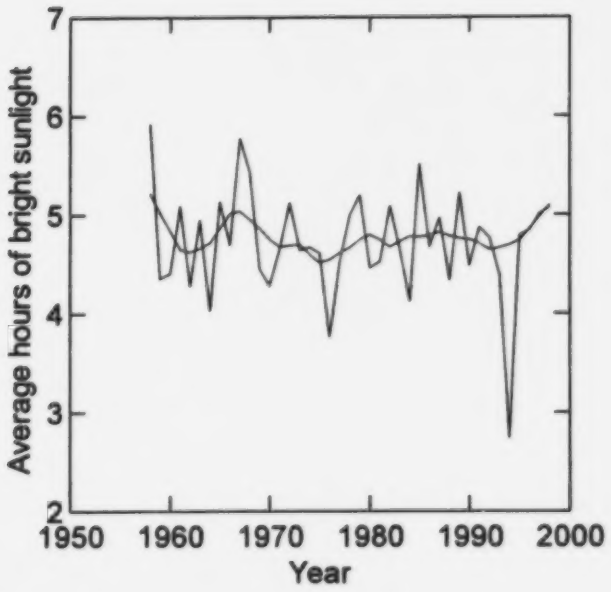

Figure 11. March-November average hours of bright sunlight per day from 1958-1998 at Buoy 185.

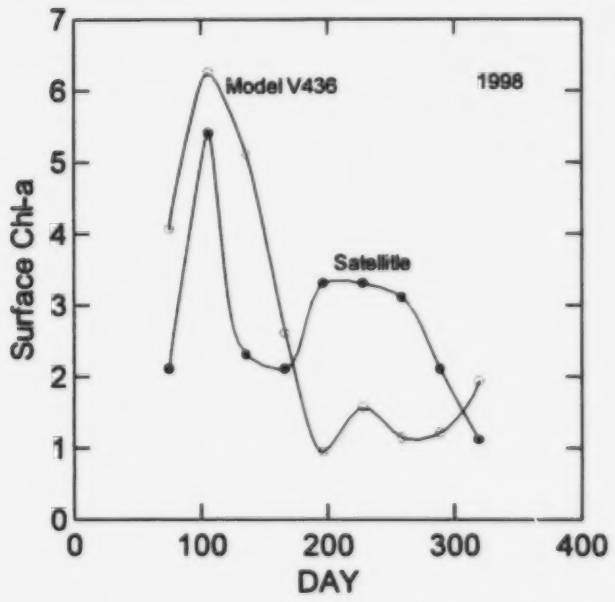

Figure 12. Monthly mean surface chl *a* concentration ($mg \cdot m^{-3}$) estimated by the model and measured by the SeaWiFS satellite in the Hecate Strait region in 1998. The model estimates the mean chl *a* in the photic zone. We assumed that the surface chl *a* concentration was 0.25*mean chl *a*.

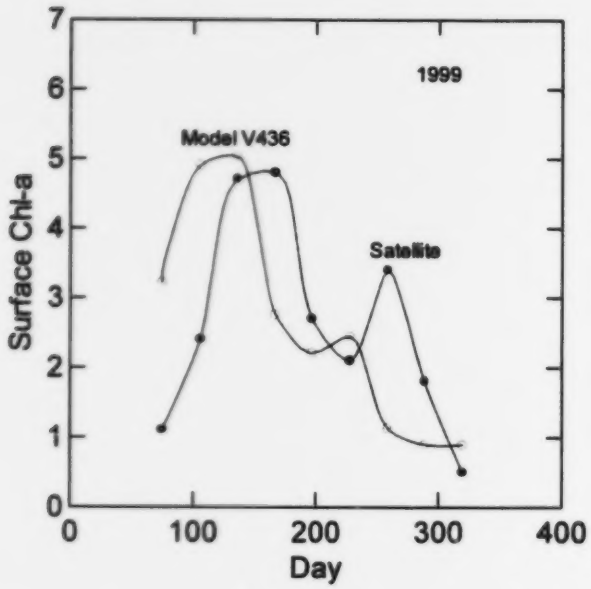

Figure 13. Monthly mean surface chl *a* concentration ($mg \cdot m^{-3}$) estimated by the model and measured by the SeaWiFS satellite in the Hecate Strait region in 1999. The model estimates the mean chl *a* in the photic zone. We assumed that the surface chl *a* concentration was 0.20*mean chl *a*.

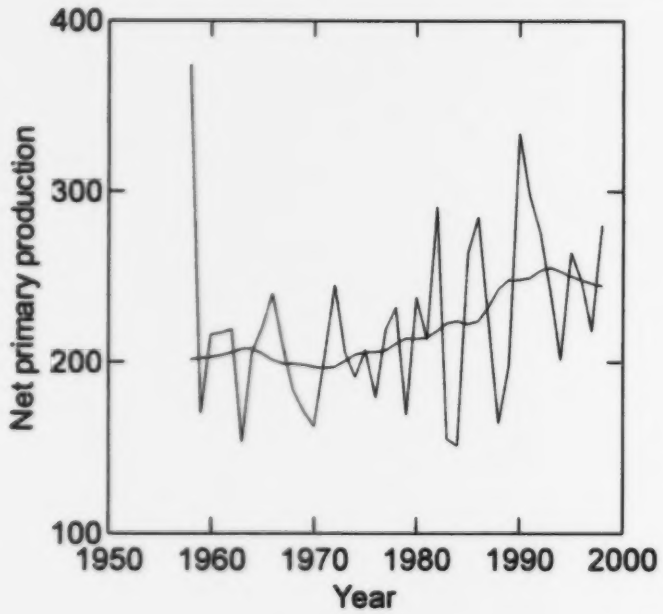

Figure 14. Net primary production ($g\ C \cdot m^{-2} \cdot yr^{-1}$) time series.

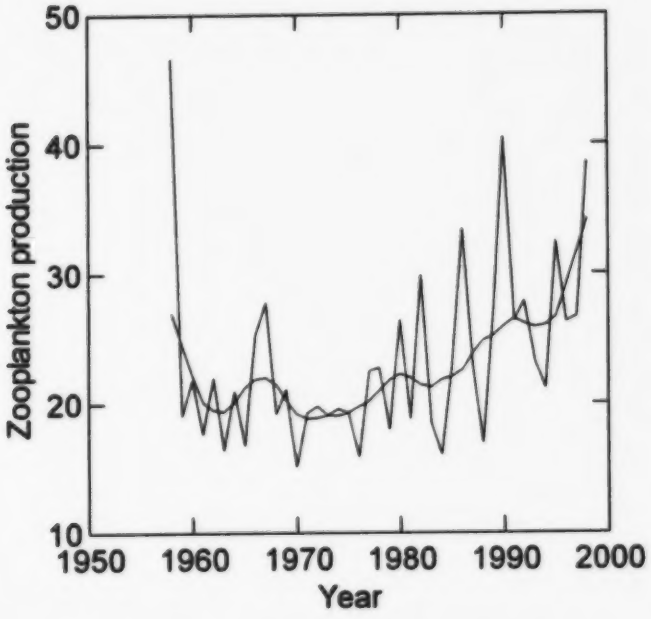

Figure 15. Total zooplankton production (g $C \cdot m^{-2} \cdot yr^{-1}$) time series.

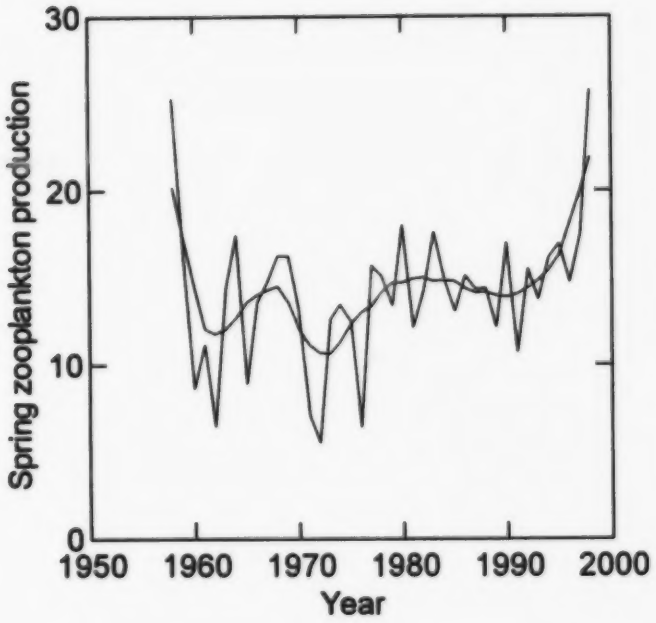

Figure 16. "Spring" zooplankton production (g $C \cdot m^{-2} \cdot yr^{-1}$) time series.

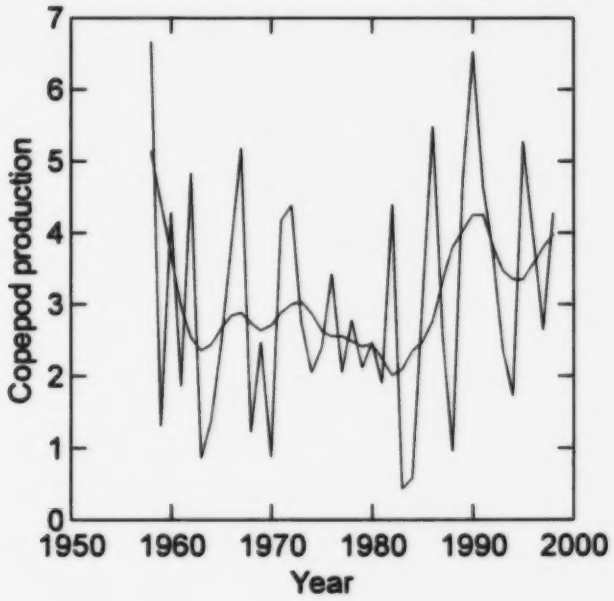

Figure 17. Copepod production (g $C \cdot m^{-2} \cdot yr^{-1}$) time series.

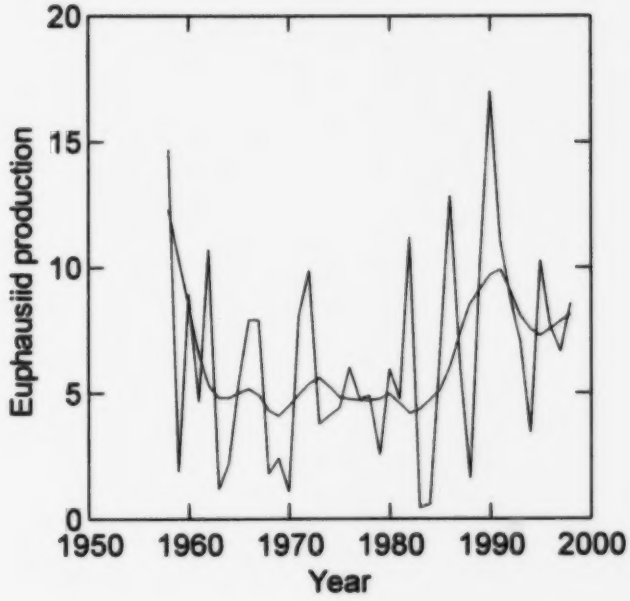

Figure 18. Euphausiid production (g $C \cdot m^{-2} \cdot yr^{-1}$) time series.

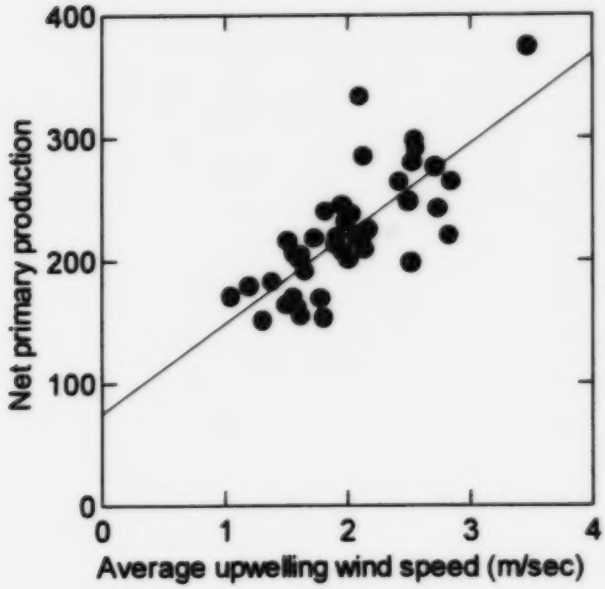

Figure 19. Relationship between net primary production (g $C \cdot m^{-2} \cdot yr^{-1}$) and upwelling wind speed ($m \cdot s^{-1}$).

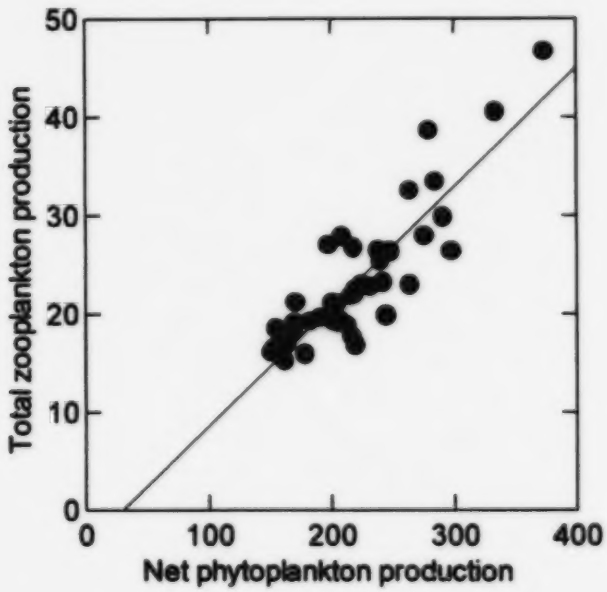

Figure 20. Relationship between net primary production (g $C \cdot m^{-2} \cdot yr^{-1}$) and total zooplankton production (g $C \cdot m^{-2} \cdot yr^{-1}$).

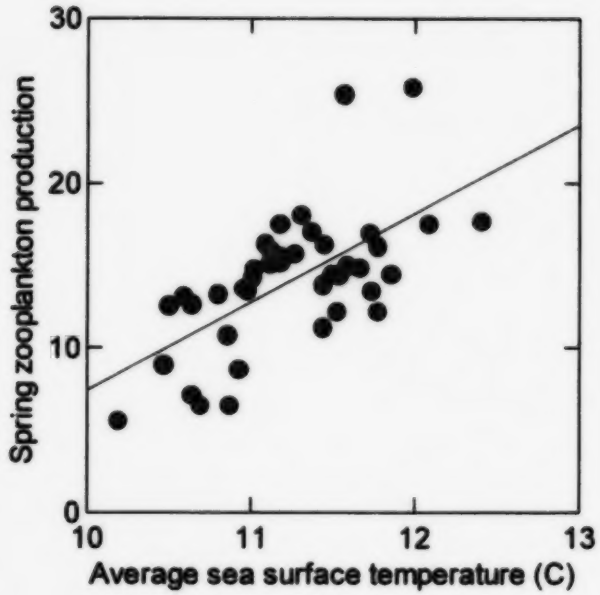

Figure 21. Relationship between average SST (°C) and annual production (g $C \cdot m^{-2} \cdot yr^{-1}$) of the "spring" zooplankton.

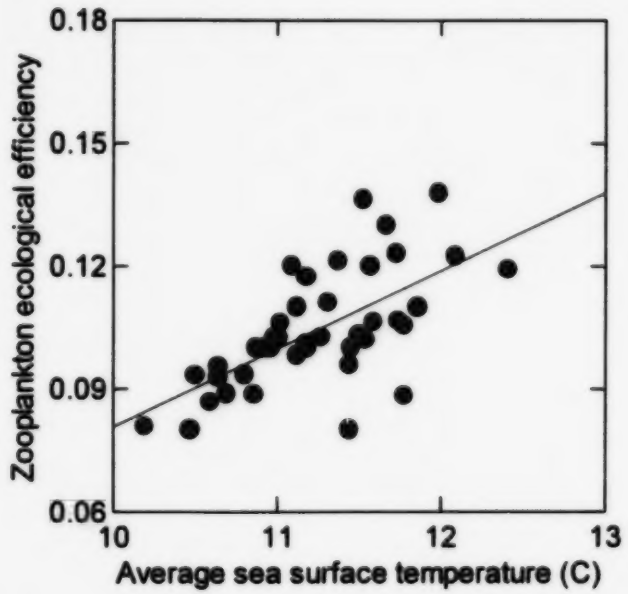

Figure 22. Relationship between zooplankton ecological efficiency and the average SST (°C).

Appendix A: Seasonal Averages of Climate Data

Table A1. Seasonal averages of climate data [March 1 (Day 60) to Nov. 30 (Day 335)] around Buoy 46185 (in northern Queen Charlotte Sound) and Model *Colim436* lower trophic level production estimates for 1958 to 1959. Appendix B explains the functional groups derived from IOS zooplankton data. Appendix C documents the model conversion factors that were used.

Average	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
SST (°C)									11.57	11.12
Sunlight (hrs)									5.92	4.35
A-Wind ($m \cdot s^{-1}$)									6.02	5.00
Upwelling-Wind ($m \cdot s^{-1}$)									3.47	1.56
Delta-SST (°C)									5.57	5.12
Mixing depth (m)									16.76	16.07
Photic Depth (m)									22.4	29.5
f-ratio									0.76	0.83
Sedimentation /Net PP									0.25	0.26
Phytoplankton										
Net production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)									374	170
Mean B ($g\ C \cdot m^{-2}$)									16.64	11.71
P/B_{net} (yr^{-1})									*22*	*15*
"Spring" Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)									25.31	15.9
B ($g\ C \cdot m^{-2}$)									1.09	0.86
P/B (yr^{-1})									*23*	*18*
Copepods										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)									6.67	1.30
B ($g\ C \cdot m^{-2}$)									0.202	0.062
P/B (yr^{-1})									*33*	*21*
Euphausiids										
Production($g\ C \cdot m^{-2} \cdot yr^{-1}$)									14.69	1.89
B ($g\ C \cdot m^{-2}$)									0.610	0.086
P/B (yr^{-1})									*24*	*22*
Total Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)									46.67	19.09
Ecological Efficiency									*0.12*	*0.11*

Table A2. Seasonal averages of climate data [March 1 (Day 60) to Nov. 30 (Day 335)] around Buoy 46185 (in northern Queen Charlotte Sound) and Model *Colim436* lower trophic level production estimates for 1960 to 1969. Appendix B explains the functional groups derived from IOS zooplankton data. Appendix C documents the model conversion factors that were used.

Average	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
SST (°C)	10.93	11.44	10.87	11.86	11.18	10.47	10.96	11.67	11.45	11.09
Sunlight (hrs)	4.40	5.09	4.28	4.95	4.03	5.13	4.69	5.77	5.43	4.45
A-Wind ($m \cdot s^{-1}$)	5.58	5.11	5.68	5.60	5.15	5.18	5.62	5.33	5.44	5.09
Upwelling-Wind ($m \cdot s^{-1}$)	1.51	2.12	2.08	1.81	1.62	2.83	1.82	2.14	1.38	1.05
Delta-SST (°C)	4.94	5.44	4.87	5.86	5.19	4.47	4.96	5.67	5.46	5.09
Mixing depth (m)	20.91	14.84	21.66	15.37	16.30	19.9	18.55	17.25	17.37	17.29
Photic Depth (m)	25.5	26.9	22.9	31.8	27.9	24.2	25.2	26.7	30.4	29.7
f-ratio	0.84	0.85	0.87	0.84	0.85	0.91	0.82	0.81	0.85	0.82
Sedimentation /Net PP	0.34	0.33	0.40	0.32	0.33	0.40	0.31	0.33	0.31	0.32
Phytoplankton										
Net production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	216	217	219	153	205	220	240	209	183	171
Mean B ($g\ C \cdot m^{-2}$)	13.31	11.51	15.37	10.30	12.97	13.79	13.6	14.55	11.55	12.77
P/B_{net} (yr^{-1})	***16***	***19***	***14***	***15***	***16***	***16***	***18***	***14***	***16***	***13***
"Spring" Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	8.64	11.16	6.46	14.40	17.44	8.91	13.56	14.79	16.23	16.24
B ($g\ C \cdot m^{-2}$)	0.44	0.68	0.33	0.87	0.90	0.46	0.67	0.68	0.88	0.79
P/B (yr^{-1})	***20***	***16***	***20***	***17***	***19***	***19***	***20***	***22***	***16***	***21***
Copepods										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	4.28	1.86	4.83	0.86	1.37	2.44	3.83	5.18	1.22	2.47
B ($g\ C \cdot m^{-2}$)	0.144	0.070	0.155	0.047	0.064	0.092	0.128	0.159	0.060	0.100
P/B (yr^{-1})	***30***	***27***	***31***	***18***	***21***	***27***	***30***	***33***	***20***	***25***
Euphausiids										
Production($g\ C \cdot m^{-2} \cdot yr^{-1}$)	8.93	4.65	10.72	1.18	2.18	5.45	7.91	7.90	1.79	2.41
B ($g\ C \cdot m^{-2}$)	0.361	0.170	0.419	0.053	0.096	0.214	0.322	0.368	0.083	0.128
P/B (yr^{-1})	***25***	***27***	***26***	***22***	***23***	***26***	***24***	***21***	***22***	***19***
Total Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	21.85	17.67	22.01	16.44	20.99	16.80	25.30	27.87	19.24	21.12
Ecological Efficiency	***0.10***	***0.08***	***0.10***	***0.11***	***0.10***	***0.08***	***0.10***	***0.13***	***0.10***	***0.12***

Table A3. Seasonal averages of climate data [March 1 (Day 60) to Nov. 30 (Day 335)] around Buoy 46185 (in northern Queen Charlotte Sound) and Model *Colim436* lower trophic level production estimates for 1970 to 1979. Appendix B explains the functional groups derived from IOS zooplankton data. Appendix C documents the model conversion factors that were used.

Average	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
SST (°C)	10.80	10.64	10.19	10.64	10.98	10.50	10.69	11.27	11.12	11.74
Sunlight (hrs)	4.28	4.66	5.12	4.64	4.67	4.61	3.76	4.52	5.00	5.20
A-Wind ($m \cdot s^{-1}$)	5.14	5.52	5.43	5.08	5.16	5.18	5.31	5.58	5.26	4.79
Upwelling-Wind ($m \cdot s^{-1}$)	1.59	1.60	1.96	1.56	1.65	1.97	1.20	1.91	1.99	1.78
Delta-SST (°C)	4.80	4.64	4.19	4.64	4.98	4.50	4.70	5.26	5.12	5.74
Mixing depth (m)	17.3	23.7	23.9	19.45	17.26	19.27	21.45	18.09	15.80	16.45
Photic Depth (m)	30.2	24.7	21.7	26.9	28.1	25.8	24.7	27.7	26.7	30.1
f-ratio	0.89	0.88	0.89	0.88	0.85	0.86	0.89	0.86	0.82	0.87
Sedimentation /Net PP	0.33	0.39	0.41	0.32	0.32	0.34	0.40	0.30	0.27	0.36
Phytoplankton										
Net production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	162	202	245	206	191	207	179	219	232	169
Mean B ($g\ C \cdot m^{-2}$)	10.72	13.88	15.17	12.56	12.05	13.16	12.92	12.24	12.23	12.55
P/B_{net} (yr^{-1})	*15*	*15*	*16*	*16*	*16*	*16*	*14*	*18*	*19*	*13*
"Spring" Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	13.20	7.06	5.53	12.59	13.43	12.49	6.42	15.68	15.09	13.39
B ($g\ C \cdot m^{-2}$)	0.77	0.37	0.29	0.64	0.72	0.64	0.34	0.83	0.80	0.68
P/B (yr^{-1})	*17*	*19*	*19*	*20*	*19*	*20*	*19*	*19*	*19*	*20*
Copepods										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	0.87	4.17	4.38	2.74	2.05	2.40	3.43	2.05	2.78	2.11
B ($g\ C \cdot m^{-2}$)	0.048	0.136	0.144	0.102	0.082	0.092	0.118	0.080	0.099	0.086
P/B (yr^{-1})	*18*	*31*	*30*	*27*	*25*	*26*	*29*	*26*	*28*	*25*
Euphausiids										
Production($g\ C \cdot m^{-2} \cdot yr^{-1}$)	1.06	8.05	9.89	3.77	4.10	4.41	6.03	4.76	4.89	2.53
B ($g\ C \cdot m^{-2}$)	0.049	0.336	0.379	0.174	0.169	0.182	0.252	0.192	0.203	0.128
P/B (yr^{-1})	*22*	*24*	*26*	*22*	*24*	*24*	*24*	*25*	*24*	*20*
Total Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	15.13	19.28	19.80	19.10	19.58	19.30	15.88	22.49	22.76	18.03
Ecological Efficiency	*0.09*	*0.10*	*0.08*	*0.09*	*0.10*	*0.09*	*0.09*	*0.10*	*0.10*	*0.11*

Table A4. Seasonal averages of climate data [March 1 (Day 60) to Nov. 30 (Day 335)] around Buoy 46185 (in northern Queen Charlotte Sound) and Model *Colim436* lower trophic level production estimates for 1980 to 1989. Appendix B explains the functional groups derived from IOS zooplankton data. Appendix C documents the model conversion factors that were used.

Average	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
SST (°C)	11.31	11.78	11.01	12.41	11.59	10.59	11.18	11.54	11.50	11.53
Sunlight (hrs)	4.46	4.52	5.09	4.65	4.12	5.51	4.67	4.97	4.33	5.22
A-Wind ($m \cdot s^{-1}$)	5.63	5.72	5.20	4.80	5.38	5.54	5.61	5.69	5.35	5.38
Upwelling-Wind ($m \cdot s^{-1}$)	2.04	1.90	2.56	1.62	1.31	2.85	2.13	2.17	1.50	2.52
Delta-SST (°C)	5.31	5.78	5.01	6.40	5.59	4.59	5.18	5.53	5.50	5.53
Mixing depth (m)	16.85	15.01	17.58	11.66	14.91	20.41	17.53	15.08	15.78	18.10
Photic Depth (m)	27.2	27.1	23.1	33.1	32.2	23.6	21.4	27.6	29.8	27.7
f-ratio	0.82	0.84	0.81	0.79	0.85	0.87	0.77	0.82	0.86	0.85
Sedimentation /Net PP	0.27	0.33	0.30	0.27	0.30	0.33	0.27	0.27	0.33	0.30
Phytoplankton										
Net production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	238	213	291	155	151	264	285	225	164	198
Mean B ($g\ C \cdot m^{-2}$)	12.13	12.49	14.48	9.27	9.85	13.81	16.73	11.23	11.06	16.15
P/B_{net} (yr^{-1})	***20***	***17***	***20***	***17***	***15***	***19***	***17***	**20**	**15**	**12**
"Spring" Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	18.00	12.14	14.23	17.61	14.91	13.07	15.11	14.32	14.39	12.16
B ($g\ C \cdot m^{-2}$)	0.92	0.74	0.67	1.07	0.90	0.68	0.69	0.81	0.82	0.55
P/B (yr^{-1})	***20***	***16***	***21***	***16***	***17***	***19***	***22***	***18***	***18***	***22***
Copepods										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	2.47	1.90	4.39	0.43	0.58	3.09	5.48	2.59	0.95	4.71
B ($g\ C \cdot m^{-2}$)	0.095	0.070	0.141	0.032	0.039	0.111	0.176	0.095	0.049	0.151
P/B (yr^{-1})	***26***	***27***	***31***	***13***	***15***	***28***	***31***	***27***	***19***	***31***
Euphausiids										
Production($g\ C \cdot m^{-2} \cdot yr^{-1}$)	5.96	4.77	11.22	0.43	0.58	6.75	12.84	6.04	1.61	10.11
B ($g\ C \cdot m^{-2}$)	0.24	0.17	0.44	0.022	0.029	0.259	0.492	0.229	0.065	0.451
P/B (yr^{-1})	***25***	***28***	***25***	***20***	***20***	***26***	***26***	***26***	***25***	***2***
										2
Total Zooplankton										
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	26.43	18.81	29.84	18.47	16.07	22.91	33.43	22.95	16.95	26.98
Ecological Efficiency	***0.11***	***0.09***	***0.10***	***0.12***	***0.11***	***0.09***	***0.12***	***0.10***	***0.10***	***0.14***

Table A5. Seasonal averages of climate data [March 1 (Day 60) to Nov. 30 (Day 335)] around Buoy 46185 (in northern Queen Charlotte Sound) and Model *Colim436* lower trophic level production estimates for 1990 to 1998. Appendix B explains the functional groups derived from IOS zooplankton data. Appendix C documents the model conversion factors that were used.

Average	1990	1991	1992	1993	1994	1995	1996	1997	1998
SST (°C)	11.37	10.86	11.18	11.44	11.78	11.73	11.02	12.09	11.99
Sunlight (hrs)	4.48	4.87	4.76	4.39	2.74	4.79	4.84	5.01	5.07
A-Wind ($m \cdot s^{-1}$)	5.00	5.50	5.62	5.36	5.49	5.47	5.89	5.18	5.37
Upwelling-Wind ($m \cdot s^{-1}$)	2.10	2.55	2.72	2.74	2.01	2.42	2.50	1.73	2.53
Delta-SST (°C)	5.37	4.86	5.18	5.44	5.78	5.73	5.02	6.09	5.99
Mixing depth (m)	16.14	20.42	15.76	16.14	15.47	16.99	20.34	16.28	13.06
Photic Depth (m)	23.1	21.6	24.5	26.8	30.7	25.1	24.0	28.4	28.3
f-ratio	0.73	0.85	0.80	0.86	0.84	0.81	0.86	0.84	0.70
Sedimentation /Net PP	0.26	0.34	0.27	0.32	0.26	0.32	0.34	0.31	0.19
Phytoplankton									
Net production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	334	293	276	242	201	264	248	218	280
Mean B ($g\ C \cdot m^{-2}$)	15.15	15.51	13.0	12.01	10.31	15.91	14.88	12.89	11.77
P/B_{net} (yr^{-1})	*27*	*23*	*23*	*23*	*19*	*17*	*17*	17	24
"Spring" Zooplankton									
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	16.97	10.71	15.50	13.75	16.09	16.92	14.74	17.47	25.75
B ($g\ C \cdot m^{-2}$)	0.76	0.51	0.80	0.74	0.91	0.75	0.70	0.82	1.22
P/B (yr^{-1})	*22*	*21*	*19*	*19*	*18*	*22*	*21*	*21*	*21*
Copepods									
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	6.53	4.64	3.70	2.38	1.72	5.27	3.96	2.64	4.27
B ($g\ C \cdot m^{-2}$)	0.196	0.146	0.126	0.091	0.072	0.165	0.132	0.098	0.140
P/B (yr^{-1})	*33*	*32*	*29*	*26*	*24*	*32*	*30*	*27*	*30*
Euphausiids									
Production($g\ C \cdot m^{-2} \cdot yr^{-1}$)	17.0	11.08	8.75	7.05	3.41	10.27	7.61	6.64	8.57
B ($g\ C \cdot m^{-2}$)	0.69	0.43	0.33	0.26	0.14	0.45	0.32	0.29	0.37
P/B (yr^{-1})	*25*	*26*	*26*	*27*	*24*	*23*	*24*	*23*	*2* *3*
Total Zooplankton									
Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	40.5	26.4	27.9	23.2	21.2	32.5	26.3	26.7	38.6
Ecological Efficiency	*0.12*	*0.09*	*0.10*	*0.10*	*0.11*	*0.12*	*0.11*	*0.12*	*0.14*

Appendix B: Seasonal Abundance Cycle of the Dominant Zooplankton

The zooplankton data were obtained from the Institute of Ocean Sciences (IOS) database. The IOS database recognizes 53 zooplankton groups. We reduced this number to 12 functional groups (Appendix Table B1).

The estimated biomass of each group was standardized to account for possible differences in day/night catches. For each of the 12 zooplankton groups we performed an ANOVA to test the hypothesis that the night and day mean biomasses were the same. To remove the effects of dusk and dawn we removed all of the samples collected between 05:00-07:00 and 20:00-22:00. We then did our ANOVA analysis on the remaining data and found no significant effect of diel migration *except* for the two euphausiid groups. For *Euphausia pacifica* we found that the night biomasses were 2.8 times higher than the day biomasses, and that night biomasses were 5.35 times greater for *Thysanoessa* species. So we added the dawn - dusk data back into the data set and applied the day correction (multiplied the day data by the correction factors) to the two euphausiids groups. Day was defined as 06:00-21:00 and night as 21:01-05:59. Day-night corrections were applied to the euphausiids and the ANOVA was rerun for the day-night data for all groups to be sure that the day and night mean biomasses were not different. None were. During this analysis it became apparent that the February mean for *Thysanoessa* was very large relative to the other means for that group. Further investigation revealed that this was due to a single very high count taken on Feb. 13, 2000 and perhaps reflected swarming. This count was one of five February samples in Queen Charlotte Sound. We decided to treat this sample as an extreme outlier and recalculated the *Thysanoessa* mean for that area and month with this sample removed.

To reduce the complexity of the model, we combined all the copepod species into a single functional group called "Copepods". Similarly, the euphausiid species were combined into a single functional group called "Euphausiids". To account for the remaining zooplankton we subtracted the monthly mean estimates of the copepod and euphausiid biomass from the total zooplankton biomass. By doing this we discovered that the biomass of the resulting species dominated the plankton community during the spring and early summer. Hence we refer to this group as the "spring" zooplankton.

Table B1 reference:

Mackas, D.L., and Galbraith, M. 1991. Zooplankton on the west coast of Vancouver Island: distribution and availability to marine birds. Pages 15-21. *In* The ecology, status, and conservation of marine shoreline birds on the west coast of Vancouver Island. Occasional Paper 75, Canadian Wildlife Service. Proceedings of a symposium sponsored by the Institute of Ocean Sciences, the Canadian Parks Service, and the Canadian Wildlife Service, held at IOS in Sydney, BC, 8 April 1991.

Table B1: Original (n = 53) IOS taxonomic categories with respect to individual weight ranges (after Mackas and Galbraith 1991) and subjective size classifications used for assignment to the 12 taxonomic groups (group names) used to summarize the data.

Group name	Taxonomic group	Weight(mg dw)
Small copepods	*Acartia clausi*	0.002-0.007
	Acartia danae	0.0015-0.005
	Acartia longiremis	0.002-0.007
	Aetideus	0.023-0.05
	Calocalanus	0.0005-0.003
	Centropages	0.005-0.03
	Clausocalanus	0.0025-0.008
	Corycaeus	0.001-0.005
	Ctenocalanus	0.004-0.012
	Mesocalanus tenuicornis	0.007-0.04
	Microcalanus	0.0015-0.0035
	Oithona spinirostris, O. atlantica	0.002-0.0035
	Oithona similis	0.0005-0.001
	Oncaea	0.002-0.004
	Paracalanus	0.0015-0.0065
	Pseudocalanus	0.0018-0.012
	Scolecithricella	0.0035-0.011
Medium Copepods	*Racovitzanus*	0.016-0.1
	Metridia pacifica	0.012-0.14
	Calanus pacificus	0.003-0.22
	Calanus marshallae	0.008-0.23
Large copepods	*Neocalanus plumchrus*	0.013-0.55
	Neocalanus cristatus	0.04-2.6
	Eucalanus bungii	0.008-0.68
	Eucalanus californicus	0.025-1.3
Chaetognatha general	Chaetognatha general	0.014-0.063
	Eukrohnia	0.18-1.4
	Sagitta decipiens, S elegans	0.1-1.0
	Sagitta scrippsae	0.18-6.5
Euphausia pacifica	Euphasiid eggs (not included in count)	
	Euphausiids (juvenile)	0.001-0.04
	Euphausia pacifica	0.65-8.5
Thysanoessa	*Thysanoessa inspinata*	0.9-10.0
	Thysanoessa spinifera	1.25-31.0
Amphipod	Amphipod *Themisto, Parathemisto*	0.75-3.7
	Amphipod *Primno*	0.32-40
Urochordates, Salps etc.	Urochordate Doliolids	0.2-1.2
	Urochordate larvae	0.01-0.2
	Urochordate Salps	7-130
Coelenterates	Coelenterates Hydrozoan medusae	0.5-60
	Coelenterates *Aurelia, Cyanea, Chrysaora*	200
	Coelenterates	0.2-15
	Ctenophores	0.9-6.9
Large items	Mollusc Pteropod *Clione*	0.5-3.5
	Polychaetes	0.04-3.5
Small items	Barnacle larvae *Cirripedia*	0.04
	Cladocera, *Evadne, Podon*	0.005
	Ostracod *Conchoecia*	0.1
	Cyphocaris	
	Mollusc Pteropod *Limacina*	0.1-1
	Mollusc Gastropoda	0.002
Remainder	Other	

Appendix C: Conversion Factors: Lower Trophic Level Model Output

- Raw model units of biomass are **mg C·m^{-3}**
- Model units are converted to **g C·m^{-2}** by multiplying mg C·m^{-3} by the depth of the euphotic zone (about 30 m) and dividing by 1000.
- To convert **g C·m^{-2}** to **tonnes(wet)·km^{-2}** we use the following ratios:
  - Phytoplankton (Various sources)
    Carbon/dry wt = 0.5
    Dry/wet wt = 0.15
    Thus, tonnes(wet)·km^{-2} = 1/(0.5*0.15) = **13.3 x g C·m^{-2}**
  - Copepods and "Spring" Zooplankton (Omori 1969)
    Carbon/dry wt = 0.52
    Dry/wet wt = 0.216
    Thus, tonnes(wet)·km^{-2} = 1/(0.52*0.216) = **8.9 x g C·m^{-2}**
  - Euphausiids (Various Sources)
    Carbon/dry wt = 0.43
    Dry/wet wt = 0.207
    Thus, tonnes(wet)·km^{-2} = 1/(0.43*0.207) = **11.2 x g C·m^{-2}**

Reference:

Omori, M. 1969. Weight and chemical composition of some important oceanic zooplankton in the North Pacific Ocean. Mar. Biol. 3: 4-10.

Hecate Strait Plankton Sample Data

- raw units = **mg(dry)·m^{-3}**
- Note that **1 tonne·km^{-2} = 1 g·m^{-2}**
- The average haul depth for the plankton samples collected in Hecate Strait/Queen Charlotte Sound that we analyzed was **107 m**.
- To convert to **tonnes·km^{-2}**:

  Divide mg(dry)·m^{-3} by dry/wet ratio = 0.17
  Multiply by haul depth = 107 m
  Divide by 1000 to convert mg(wet) to g(wet)
  Answer has units of = g·m^{-2} or tonnes·km^{-2}

  Example: 2.6 mg(dry)·m^{-3} = [(2.6/0.17) x 107 /1000] = 1.64 g·m^{-2} or tonnes·km^{-2}.
  2.6 mg(dry)·m^{-3} = **0.6294***2.6 mg(dry)·m^{-3} = 1.64 g·m^{-2} or tonnes·km^{-2}.

Appendix D: Ocean Climate Data File Available via Download

Electronic versions of this report (*"TR2656 Hecate Retrospectives 1958-1998.pdf"*) and the following Excel spreadsheet will soon be available by searching the Fisheries and Oceans Canada "Waves" library (http://inter01.dfo-mpo.gc.ca/waves2/search.html) online for this report. Once your search locates the report, choose "View Online" from the DFO Internet Copy near the bottom left of the web page to then select the files you wish to download.

File Name	Contents	Page #
Buoy185 ocean climate data.xls	Daily ocean climate data for 1991-2000 from Buoy 185, plus hours of sunlight reported from Port Hardy	6